PATENT COOPERA 'N TREATY

From the INTERNATIONAL BUREAU

PCT

COMMUNICATION OF
INTERNATIONAL APPLICATIONS

(PCT Article 20)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark
Office, PCT
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CP2/5C24
Arlington, VA 22202
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in its capacity as designated Office

Date of mailing:
11 June 2001 (11.06.01)

The International Bureau transmits herewith copies of the international applications having the following international application numbers and international publication numbers:

International application no.:	International publication no.:
PCT/SG99/00139	

The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland

Facsimile No.: (41-22) 740.14.35

Authorized officer:

J. Zahra

Telephone No.: (41-22) 338.83.38

PCT

REQUEST

RECORD COPY

The undersigned requests that the present international application be processed according to the Patent Cooperation Treaty.

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PCT/SG 99 / 00139

International Application No.

08 DECEMBER 1999 (08-12-99)

International Filing Date

REGISTRY OF PATENTS (SINGAPORE)
PCT INTERNATIONAL APPLICATION

Name of receiving Office and "PCT International Application"

Applicant's or agent's file reference
(if desired) (12 characters maximum) FP1157

Box No. I TITLE OF INVENTION

Apparatus for Detecting the Oscillation Amplitude of an Oscillating Object

Box No. II APPLICANT

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

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This person is applicant for the purposes of: ☐ all designated States ☒ all designated States except the United States of America ☐ the United States of America only ☐ the States indicated in the Supplemental Box

Box No. III FURTHER APPLICANT(S) AND/OR (FURTHER) INVENTOR(S)

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

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This person is:

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☐ inventor only *(If this check-box is marked, do not fill in below.)*

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This person is applicant for the purposes of: ☐ all designated States ☐ all designated States except the United States of America ☒ the United States of America only ☐ the States indicated in the Supplemental Box

☒ Further applicants and/or (further) inventors are indicated on a continuation sheet.

Box No. IV AGENT OR COMMON REPRESENTATIVE; OR ADDRESS FOR CORRESPONDENCE

The person identified below is hereby/has been appointed to act on behalf of the applicant(s) before the competent International Authorities as: ☒ agent ☐ common representative

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PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTICE INFORMING THE APPLICANT OF THE COMMUNICATION OF THE INTERNATIONAL APPLICATION TO THE DESIGNATED OFFICES

(PCT Rule 47.1(c), first sentence)

To:

MCCALLUM, Graeme, David
Lloyd Wise
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P.O. Box 636
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LLOYD WISE
20 JUN 2001
RECEIVED

Date of mailing (day/month/year) 11 June 2001 (11.06.01)		
Applicant's or agent's file reference FP1157	**IMPORTANT NOTICE**	
International application No. PCT/SG99/00139	International filing date (day/month/year) 08 December 1999 (08.12.99)	Priority date (day/month/year)
Applicant ASM TECHNOLOGY SINGAPORE PTE LTD. et al		

1. Notice is hereby given that the International Bureau has communicated, as provided in Article 20, the international application to the following designated Offices on the date indicated above as the date of mailing of this Notice:
   US

   In accordance with Rule 47.1(c), third sentence, those Offices will accept the present Notice as conclusive evidence that the communication of the international application has duly taken place on the date of mailing indicated above and no copy of the international application is required to be furnished by the applicant to the designated Office(s).

2. The following designated Offices have waived the requirement for such a communication at this time:
   None

   The communication will be made to those Offices only upon their request. Furthermore, those Offices do not require the applicant to furnish a copy of the international application (Rule 49.1(a-bis)).

REMINDER REGARDING CHAPTER II (Article 31(2)(a) and Rule 54.2)

If the applicant wishes to postpone entry into the national phase until 30 months (or later in some Offices) from the priority date, a demand for **international preliminary examination** must be filed with the competent International Preliminary Examining Authority before the expiration of 19 months from the priority date.

It is the applicant's sole responsibility to monitor the 19-month time limit.

Note that only an applicant who is a national or resident of a PCT Contracting State which is bound by Chapter II has the right to file a demand for international preliminary examination.

REMINDER REGARDING ENTRY INTO THE NATIONAL PHASE (Article 22 or 39(1))

If the applicant wishes to proceed with the international application in the **national phase**, he must, within 20 months or 30 months, or later in some Offices, perform the acts referred to therein before each designated or elected Office.

For further important information on the time limits and acts to be performed for entering the national phase, see the Annex to Form PCT/IB/301 (Notification of Receipt of Record Copy) and Volume II of the PCT Applicant's Guide.

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland	Authorized officer J. Zahra
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Continuation of Box No. III	FURTHER APPLICANT(S) AND/OR (FURTHER) INVENTOR(S)

If none of the following sub-boxes is used, this sheet should not be included in the request.

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This person is applicant for the purposes of: [ ] all designated States [ ] all designated States except the United States of America [X] the United States of America only [ ] the States indicated in the Supplemental Box

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- [X] applicant and inventor
- [ ] inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality: Singapore

State *(that is, country)* of residence: Singapore

This person is applicant for the purposes of: [ ] all designated States [ ] all designated States except the United States of America [X] the United States of America only [ ] the States indicated in the Supplemental Box

[ ] Further applicants and/or (further) inventors are indicated on another continuation sheet.

Box No. V DESIGNATION OF STATES

The following designations are hereby made under Rule 4.9(a) *(mark the applicable check-boxes; at least one must be marked)*:

Regional Patent

☒ **AP** ARIPO Patent: GH Ghana, GM Gambia, KE Kenya, LS Lesotho, MW Malawi, SD Sudan, SL Sierra Leone, SZ Swaziland, UG Uganda, ZW Zimbabwe, and any other State which is a Contracting State of the Harare Protocol and of the PCT

☒ **EA** Eurasian Patent: AM Armenia, AZ Azerbaijan, BY Belarus, KG Kyrgyzstan, KZ Kazakhstan, MD Republic of Moldova, RU Russian Federation, TJ Tajikistan, TM Turkmenistan, and any other State which is a Contracting State of the Eurasian Patent Convention and of the PCT

☒ **EP** European Patent: AT Austria, BE Belgium, CH and LI Switzerland and Liechtenstein, CY Cyprus, DE Germany, DK Denmark, ES Spain, FI Finland, FR France, GB United Kingdom, GR Greece, IE Ireland, IT Italy, LU Luxembourg, MC Monaco, NL Netherlands, PT Portugal, SE Sweden, and any other State which is a Contracting State of the European Patent Convention and of the PCT

☒ **OA** OAPI Patent: BF Burkina Faso, BJ Benin, CF Central African Republic, CG Congo, CI Côte d'Ivoire, CM Cameroon, GA Gabon, GN Guinea, GW Guinea-Bissau, ML Mali, MR Mauritania, NE Niger, SN Senegal, TD Chad, TG Togo, and any other State which is a member State of OAPI and a Contracting State of the PCT *(if other kind of protection or treatment desired, specify on dotted line)* ....

National Patent *(if other kind of protection or treatment desired, specify on dotted line)*:

- ☒ AE United Arab Emirates
- ☒ AL Albania ....
- ☒ AM Armenia ....
- ☒ AT Austria ....
- ☒ AU Australia ....
- ☒ AZ Azerbaijan
- ☒ BA Bosnia and Herzegovina ....
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- ☒ UG Uganda ....
- ☒ US United States of America ....
- ☒ UZ Uzbekistan ....
- ☒ VN Viet Nam ....
- ☒ YU Yugoslavia ....
- ☒ ZA South Africa ....
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Check-boxes reserved for designating States which have become party to the PCT after issuance of this sheet:

- ☐ ....
- ☐ ....

CONSIDERED WITHDRAWN BY THE RECEIVING OFFICE

Precautionary Designation Statement: In addition to the designations made above, the applicant also makes under Rule 4.9(b) all other designations which would be permitted under the PCT except any designation(s) indicated in the Supplemental Box as being excluded from the scope of this statement. The applicant declares that those additional designations are subject to confirmation and that any designation which is not confirmed before the expiration of 15 months from the priority date is to be regarded as withdrawn by the applicant at the expiration of that time limit. *(Confirmation of a designation consists of the filing of a notice specifying that designation and the payment of the designation and confirmation fees. Confirmation must reach the receiving Office within the 15-month time limit.)*

Box No. VI PRIORITY CLAIM ☐ Further priority claims are indicated in the Supplemental Box.

Filing date of earlier application *(day/month/year)*	Number of earlier application	Where earlier application is: national application: country	regional application:* regional Office	international application: receiving Office
item (1)				
item (2)				
item (3)				

☐ The receiving Office is requested to prepare and transmit to the International Bureau a certified copy of the earlier application(s) *(only if the earlier application was filed with the Office which for the purposes of the present international application is the receiving Office)* identified above as item(s): ________

* *Where the earlier application is an ARIPO application, it is mandatory to indicate in the Supplemental Box at least one country party to the Paris Convention for the Protection of Industrial Property for which that earlier application was filed (Rule 4.10(b)(ii)). See Supplemental Box.*

Box No. VII INTERNATIONAL SEARCHING AUTHORITY

Choice of International Searching Authority (ISA) *(if two or more International Searching Authorities are competent to carry out the international search, indicate the Authority chosen; the two-letter code may be used)*:

ISA / AT

Request to use results of earlier search; reference to that search *(if an earlier search has been carried out by or requested from the International Searching Authority)*:

Date *(day/month/year)* Number Country *(or regional Office)*

Box No. VIII CHECK LIST; LANGUAGE OF FILING

This international application contains the following number of sheets:

request	: 4
description (excluding sequence listing part)	: 15
claims	: 4
abstract	: 1
drawings	: 8
sequence listing part of description	:
Total number of sheets	: 32

This international application is accompanied by the item(s) marked below:

1. ☒ fee calculation sheet
2. ☐ separate signed power of attorney
3. ☐ copy of general power of attorney; reference number, if any:
4. ☐ statement explaining lack of signature
5. ☐ priority document(s) identified in Box No. VI as item(s):
6. ☐ translation of international application into (language):
7. ☐ separate indications concerning deposited microorganism or other biological material
8. ☐ nucleotide and/or amino acid sequence listing in computer readable form
9. ☒ other *(specify)*: PF48

Figure of the drawings which should accompany the abstract: 2

Language of filing of the international application: English

Box No. IX SIGNATURE OF APPLICANT OR AGENT

Next to each signature, indicate the name of the person signing and the capacity in which the person signs (if such capacity is not obvious from reading the request).

McCALLUM, GRAEME DAVID
AGENTS FOR THE APPLICANTS

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1. Date of actual receipt of the purported international application: 08 DECEMBER 1999 (08-12-99)
2. Drawings: ☒ received: ☐ not received:
3. Corrected date of actual receipt due to later but timely received papers or drawings completing the purported international application:
4. Date of timely receipt of the required corrections under PCT Article 11(2):
5. International Searching Authority (if two or more are competent): ISA / AT
6. ☐ Transmittal of search copy delayed until search fee is paid.

For International Bureau use only

Date of receipt of the record copy by the International Bureau: 17 JAN 2000 17 JANVIER 2000

Apparatus for Detecting the Oscillation Amplitude of an Oscillating Object

The invention relates to apparatus for detecting the oscillation amplitude of an oscillating object and in particular, the oscillation amplitude of the capillary tip of an ultrasonic transducer for ultrasonic welding.

During the semiconductor packaging process a semiconductor die (or chip) is bonded to a metal leadframe. This is commonly known as die attachment. Conductive wire is then bonded between electrical contact pads on the die and electrical contacts on the leadframe by a piece of equipment commonly known as a wire bonder. The wire bonder bonds the conductive wire to the die and the leadframe by an ultrasonic welding process, which uses an ultrasonic wave transducer. The ultrasonic wave transducer has a capillary working tip mounted on it and the conductive wire passes through a through bore in the capillary to the capillary tip. It is the tip, which applies the ultrasonic vibration from the transducer to the conductive wire to form the bond. The transducer generates longitudinal vibration of the capillary tip, which bonds the wire onto the die pad or the leadframe.

The oscillation amplitude of the capillary tip has been identified as one of the critical parameters necessary to achieve consistent bonding results. Due to the very small size of the capillary tip and the complex vibration pattern, it is difficult to accurately measure the vibration amplitude of the capillary tip in both free (unloaded) vibration mode and loaded vibration mode. A further complication is that different capillaries used in different transducers have different vibration patterns. A large number of

attempts have been made in recent years to develop systems to measure the oscillation amplitude accurately.

However, these systems either can not perform real-time measurement or involve a complex series of operations in a controlled environment. With some of the systems it is even necessary to switch off the wire bonder during the measurement process.

For example, US Patent No. 5,199,630 measures the transducer's vibration amplitude by using an opto-electronic receiver and a corresponding electronic controller. To perform the measurement, the apparatus must be re-calibrated every time and thus cannot perform real-time measurement. To measure the transducer's vibration, the apparatus must be fixed to the bonding area of the wire bonder. The apparatus needs to be removed from the bonder after measurement for normal operation of the wire bonder. Hence, the apparatus can not be used to measure the oscillation amplitude during an actual wire bonding operation. Therefore, this apparatus is not practical to conduct frequent amplitude measurements.

This apparatus is also sensitive to the ambient temperature during the measurement process as it measures only the optical power variation due to the vibration of the transducer. Therefore, this apparatus is not convenient to use in an industrial environment where the temperatures in the vicinity of the capillary tip can be high due to the bonding operation.

Furthermore, the apparatus disclosed in US 5,199,630 measures the oscillation amplitude of the ultrasonic transducer that holds the capillary tip, not the vibration amplitude of the actual capillary tip. When one capillary is replaced with a new capillary, for example due to wear of the capillary or a different capillary is needed to bond a new device, the actual vibration of the capillary may be different.

Therefore, the measurement of the oscillation amplitude of the transducer cannot be used to precisely monitor the quality of the bond, as the oscillation amplitude measured does not accurately reflect the oscillation amplitude of the capillary tip.

In accordance with a first aspect of the present invention, apparatus for detecting the oscillation amplitude of an oscillating object comprises an optical radiation source; a detector comprising first and second optical radiation sensing areas adjacent each other, the detector and the optical radiation source adapted to be located opposite each other with the oscillating object located between the source and the detector so that the object blocks a portion of the sensing areas from receiving optical radiation from the source; and a processor coupled to the detector to receive first and second output signals representing the magnitude of optical radiation sensed by the first and second optical radiation sensing areas, respectively; the processor processing the first and second output signals to obtain an indication of the amplitude of oscillation of the object.

In accordance with a second aspect of the present invention, a method of detecting the oscillation amplitude of an oscillating object comprises positioning an optical

radiation source and an optical radiation detector on opposite sides of the object, the detector comprising first and second optical radiation sensing areas; illuminating the object with optical radiation from the source and processing first and second output signals from the first and the second optical radiation sensing areas to determine the oscillation amplitude of the object.

The term "optical radiation" as used herein covers electromagnetic radiation in the visible, ultraviolet and infrared regions of the electromagnetic spectrum.

An advantage of the invention is that it permits the amplitude of oscillation of a capillary tip of an ultrasonic bonder to be measured without influencing the vibration of the capillary tip. This enables real-time measurement of the vibration amplitude of the capillary tip of a wire bonder and enables the transducer to be calibrated to produce consistent vibration amplitude of the capillary tip and to thereby improve the bond quality.

Preferably, the oscillating object is a tip of an ultrasonic transducer in an ultrasonic welding machine. Typically, where the ultrasonic welding machine is a wire bonder, the tip is a capillary tip.

Typically, the processor may generate an output oscillation signal, which can be applied to the oscillating object to modify the oscillation amplitude of the object in response to the oscillation amplitude detected by the processor. This has the advantage that as well as measuring the oscillation amplitude, the apparatus may

also control the oscillation amplitude in response to the measured oscillation amplitude.

Preferably, the output oscillation signal is input to a control device that controls oscillation of the object. Typically, where the oscillating object is a tip of an ultrasonic transducer, the control device comprises an ultrasonic wave controller.

Typically, the control device compares the oscillation amplitude with a reference oscillation amplitude and controls the oscillation of the object so that the object oscillates at substantially the reference oscillation amplitude. Preferably, the control device controls the oscillation amplitude in real time.

Typically, the optical radiation source comprises a collimating device to collimate the optical radiation exiting the source.

Preferably, the width of each of the first and second optical radiation sensing areas is greater than the sum of half the width of the oscillating object and the amplitude of oscillation of the object. Typically, the amplitude of oscillation is less than the width of the oscillating object.

In one example of the invention, the first and second optical radiation sensing areas are directed towards the optical radiation source. Typically, the first and second optical radiation sensing areas are adjacent each other. The optical radiation

sensing areas may be coplanar. Typically, the spacing between the first and second radiation sensing areas is not greater than 10% of the width of the oscillating object. Preferably, the spacing is less than 10% and is kept to minimum.

In an alternative example of the invention, the first and second optical radiation sensing areas are not directed towards the optical radiation source and the detector further comprises an optical device to direct the optical radiation onto the first and second sensing areas.

Preferably, the processor generates an indication of the oscillation amplitude by comparing the sum of the first and second output signals with the difference between the first and second output signals.

Typically, the first and second optical radiation sensing areas each comprise a photodiode.

An example of apparatus for measuring the oscillation amplitude of an oscillating object in accordance with the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a perspective view of an ultrasonic transducer and an optical radiation source and detector;

Figure 2 is a schematic view of the transducer of Figure 1 and oscillation measuring apparatus incorporating the source and detector shown in Figure 1;

Figure 3 is a block diagram of the apparatus shown in Figure 2 with a measurement process unit shown in more detail;

Figure 4 is a front view of the detector shown in Figure 1;

Figure 5 is a cross-sectional view of the detector of Figure 4 in use;

Figure 6 is a cross-sectional view of another example of a detector in use;

Figures 7A, 7B and 7C are schematic diagrams showing a capillary bonding tip in a central position, a left hand position and a right side position, respectively, with respect to the detector shown in Figure 4;

Figure 8 is a graph of the output signal from the detector of Figure 4 versus capillary tip position in the Y direction;

Figure 9 is a graph of the output signal from the detector of Figure 4 versus capillary tip position in the Z direction; and

Figure 10 shows a vibration profile of a capillary in free vibration; and

Figure 11 shows a vibration profile of a capillary during wire bonding.

Figure 1 shows an ultrasonic transducer 1 having a capillary 2 with a tip 3. In Figure 1 the capillary 2 is shown in a larger scale relative to the transducer 1 for clarity and to show the shape of the capillary 2. The capillary 2 is located within a hole 4 in the end of the transducer 1 so that the longitudinal axis of the capillary 2 is at approximately right angles to the longitudinal axis of the transducer 1. The capillary 2 is removably inserted into the hole 4 and held in the hole 4, for example by means of a locking screw (not shown).

The transducer 1 and capillary 2 form part of a bond head of a wire bonder for bonding conductive wire to semiconductor dies and leadframes. The wire to be bonded passes through a through bore 5 in the capillary 2, which is coincident with the longitudinal axis 6, and extends out of the tip 3. Figure 1 also shows a sensor head 7 comprising a body 8 on which is mounted an optical radiation emitter 9 and an optical radiation detector 10.

Also shown in Figure 1, for reference purposes only, is a set of X-Y-Z co-ordinates 11. In use, during wire bonding (i.e. during ultrasonic welding of wire at the capillary tip 3 to a semiconductor die or a leadframe) the transducer 1 oscillates (or vibrates) in the Y direction with respect to the sensing head 7. This vibration has been identified as being the most important vibration contribution to the bond quality. In addition, the transducer 1 and capillary 2 may be moved up and down in the Z direction, with respect to the sensing head 7, to bring the tip 3 into contact with the surface to which the wire is to be bonded.

Figure 2 shows oscillation measurement apparatus 12 including the sensor head 7 (shown in phantom) with the transducer 1 and capillary 2. The orientation of the sensing head 7 is as viewed in the Y direction shown in Figure 1. Although in Figure 2 the transducer 1 is shown with its longitudinal axis extending in the X direction, this is for the purposes of clarity only and the longitudinal axis of the transducer would extend in the Y direction in use, as shown in Figure 1. As shown in Figure 2, the emitter 9 comprises an optical radiation source 13 and collimating optics 14. Hence, the emitter 9 generates a collimated beam 15 of optical radiation.

The detector 10 generates a first output signal V_A and a second output signal V_B which are fed to a measurement process unit 18. The measurement process unit 18 is coupled to a system controller 19 which in turn is coupled to an ultrasonic wave generator 20. The ultrasonic wave controller 20 generates an output 21 that is fed to the bond head 22 to control the amplitude of oscillation of the transducer 1 and thereby control the oscillation amplitude of the tip 3.

Figure 3 shows the detector 10 and the unit 18 in more detail. In this figure, the sensing head 7 is as viewed in the Z direction of Figure 1. The detector 10 comprises an optical aperture 23 and two photodiodes 24A, 24B located behind the optical aperture 23. Figure 5 shows a more detailed cross-sectional view of the detector 10 and capillary tip 3. The photodiodes 24 are mounted on a support 26. The photodiodes 24A, 24B generate the first and second output signals V_A, V_B respectively. The output signals V_A, V_B are in the form of voltage signals whose magnitude is indicative of the magnitude of optical radiation detected by the respective photodiode 24.

The unit 18 includes two amplifiers 35. Each amplifier 35 receives one of the output signals V_A, V_B , amplifies the signal and outputs the respective amplified signal VA, VB to a summing device 26 and a subtraction device 27. The summing device 26 sums the signals VA, VB and outputs the sum V_{AB} (=VA + VB) to the system controller 19 and to a difference device 28. The subtraction device 27 subtracts the signals VA, VB and outputs a signal S_{AB} (which is equal to the magnitude of the

subtracted signals) to the difference device 28. The difference device 28 generates an output signal V'. This is defined as follows:

$$V' = \frac{S_{AB}}{V_{AB}} = \frac{V_A - V_B}{V_A + V_B}$$

The output signal V' is output to a bandpass filter 29 and a lowpass filter 30. The signals V_A, V_B from the photodiodes 24A, 24B typically comprise a DC component and an AC component. Hence, the output V' of the difference device 28 also includes AC and DC components. Therefore, V' can be separated into a DC component V_{DAB} and an AC component V_{AC}. That is $V' = V_{DAB} + V_{AC}$.

The lowpass filter 30 removes the AC component and so outputs the DC component V_{DAB} to the system controller 19. V_{DAB} is used to position the capillary tip 3 in the Y direction and to calibrate the system during assembly.

The bandpass filter 29 removes the DC component and so outputs the AC component V_{AC} to an RMS device 31 which converts the AC component V_{AC} to a DC signal V_{AAB} which is proportional to the amplitude of the AC component V_{AC}.

In general, the output current of the photodiodes 24 is proportional to the received power of the optical radiation. This is proportional to the effective sensing area, assuming uniform optical radiation intensity I_O over the whole of the effective sensing area. The output current is converted to a proportional voltage signal V. For the system described herein and shown in the drawings, V_A and V_B are proportional to the total sensing area of the detectors 24A, 24B respectively. During measurement,

the total effective sensing area stays constant. Therefore, V_{AB} is proportional to the optical radiation intensity I_O.

V_{AB} is also used as a reference signal to correctly position the capillary tip 3 with respect to the photodiodes 24A, 24B, as described below.

The system controller 19 receives the output signals from the process unit 18. Based on the parameters set in the system controller 19 and the signals received from the process unit 18, the system controller 19 calculates the necessary control parameters to drive the ultrasonic wave controller 20. In response to the control parameters received from the system controller 19, the ultrasonic wave controller 20 outputs the signal 21 to control the amplitude of oscillation of the capillary tip 3 by controlling the oscillation of the ultrasonic transducer 1.

To measure the oscillation amplitude of the capillary tip 3, the capillary tip 3 is positioned between the emitter 9 and the detector 10, as shown in Figures 1 to 3. The collimated light beam 15 illuminates the capillary tip 3 and projects a shadow of the capillary tip 3 onto the detector 10. As shown in Figure 4, the photodiodes 24A, 24B each have a net effective or active sensing area 25A, 25B. The sensing areas 25 face towards the emitter 9 so that collimated light 15 entering the aperture 23 is detected by the sensing areas 25. The aperture 23 is large enough so that the shadow image of the capillary tip 3 (see Figures 7A, 7B and 7C) is positioned within the aperture 23 during measurement but small enough to maintain high resolution. The collimated light beam 15 must be large enough so that part of the collimated light

beam 15 passing through the aperture 23 projects an even illumination covering the combined width W of the sensing areas 25 of the photodiodes 24 and the height H of the sensing areas 25 of the photodiodes 24, as shown in Figure 4. The width W and height H, together with the separation δW of the sensing areas 25, determine the sensitivity and measuring range of the apparatus 12. The two photodiodes 24 are placed very closely behind the aperture 23. The separation δW of the sensing areas 25 is typically of the order of 10μm to 100μm. The output signals V_A and V_B are proportional to the total optical power detected by the respective photodiode 24A, 24B, and therefore, the proportion of the light beam 15 incident on the respective sensing area 25A, 25B.

The output voltage V_{AB} generated by the summing device 26 is used as a reference signal to position the capillary in the sensor head 7. Before the capillary tip 3 is positioned in the sensor head 7, the voltage V_{AB} is equal to U'_{SUM}. A pre-defined constant β is used to determine if the capillary tip 3 is correctly aligned in the sensor head 7. When the capillary tip 3 is aligned correctly, the voltage V_{AB} is equal to $U_{SUM}=\beta U'_{SUM}$ where β is a pre-defined value ranging from 0.5 to 0.8 and is dependent on the expected sensitivity and measurement range of the apparatus 12. In this way, the measurement can be made at the same section of the capillary tip 3 for the same type of capillaries.

To align the tip 3 for the Y direction, firstly the voltage V_{AB} is measured without the tip 3 in the sensor head 7. The tip 3 is then moved into the sensor head 7, and V_{AB} is monitored by the system controller 19. When the V_{AB} starts to fall which corresponds

to position Y1 in Figure 8, the capillary tip 3 is then inserted a further distance of W/2. The position of the capillary tip can be fine adjusted by using the voltage signal V_{DAB}. When the capillary tip is positioned correctly in the centre of the sensing areas, V_{DAB} will be equal to zero or will be at a minimum value. The system controller 19 records this Y position for reference as Y_{CENTRE}.

To align the tip 3 in the Z direction, firstly the voltage V_{AB} is measured without the tip 3 in the sensor head 7. This is indicated as position Z1 in Figure 9. The tip 3 is then lowered into the head 7 along the Z direction towards the centre of the sensing areas 25 according to the Y reference position Y_{CENTRE} while continuously monitoring the value of V_{AB}. The capillary tip 3 is in the correct Z position when V_{AB} is equal to U_{SUM} where $U_{SUM}=\beta U'_{SUM}$. The correct Z position is shown as position Z2 in Figure 9, where it can be seen that the tip 3 partially covers the sensing areas 25A, 25B.

The Y and Z direction alignment can be done manually or automatically. Preferably, it is performed automatically by the system controller 19 and bond header according to the parameters.

The oscillation of the capillary tip 3 is controlled by the system controller 19 via the ultrasonic wave controller 20 which drives the oscillation of the transducer 1 in response to signals received from the system controller 19. When the capillary tip 3 oscillates in the Y direction, the shadow of the tip 3 on the sensing areas 25 also moves, as shown in Figures 7A to 7C. In Figures 7A to 7C, the tip 3 has an oscillation amplitude of δY and the point of the tip 3 has an angle of 2α.

Hence, the light power detected by each photodiode changes during an oscillation cycle of the tip 3 and the corresponding output signal V_A, V_B changes accordingly. However, the output V_{AB} from the summing device 26 will remain constant.

The output signals V_A, V_B are fed to the processing unit 18 where they are amplified by the respective amplifiers 35. The signals V_A, V_B are processed as described above in the processing unit 18 to obtain the three output signals V_{AB}, V_{DAB}, V_{AAB}.

V_{DAB} indicated if the capillary tip was positioned in the centre of window of sensor' receiver. V_{AAB} is directly proportional to the vibration amplitude δY of capillary tip according to following equation:

$$\delta Y=\gamma_{AC}V_{AAB}$$

where γ_{AC} is the sensitivity of the apparatus 12. The value of γ_{AC} is calculated according to the following equation:

$$\gamma_{AC}=\beta(W-\delta W)/2M$$

where M is a constant of the processing unit 18. M is determined by the amplification of the processing unit 18. β is the pre-defined constant referred to above and is equal to U_{SUM}/U'_{SUM}. Therefore, the sensitivity of the apparatus 12 is dependent only on the width W and the separation δW, as M and β are both constants.

An alternative example of a detector 40 is shown in Figure 6. In this example the detector 40 includes two photodiodes 24A, 24B which face each other. The light

beam 15 is reflected onto the photodiodes by a reflecting device 41 mounted on a support 42. Hence, actual detection and operation of the detector 40 is identical to that for the detector 10 except that the separation δW is nearly equal to zero.

By means of the feedback system obtained by coupling the processing unit 18 to the system controller 19, it is possible to adjust the oscillation amplitude of the capillary tip 3, in real time, until the amplitude is at a desired value. In addition, due to the compact nature of the sensor head 7 it is possible to measure the oscillation amplitude of the tip 3 at any time during operation of the wire bonder, including during an actual wire bond operation. This is important as the oscillation (or vibration) profile of the tip 3 is different depending on whether the tip 3 is in free vibration (i.e. not contacting a bonding surface) or performing a wire bond operation, as shown in Figures 10 and 11, respectively. Therefore, this enables optimisation of the oscillation amplitude and a more consistent bonding process with a reduction in the number of faulty bonds.

Other advantages of the invention are that it mitigates the effect of temperature fluctuations and does not require re-calibration before each measurement. In addition, as the measurement process can be performed during the wire bond operation it is not necessary to stop or switch off the bonder to perform the measurement. This reduces the downtime of the wire bonder.

Claims

1. Apparatus for detecting the oscillation amplitude of an oscillating object, the apparatus comprising an optical radiation source; a detector comprising first and second optical radiation sensing areas adjacent each other, the detector and the optical radiation source adapted to be located opposite each other with the oscillating object located between the source and the detector so that the object blocks a portion of the sensing areas from receiving optical radiation from the source; and a processor coupled to the detector to receive first and second output signals representing the magnitude of optical radiation sensed by the first and second optical radiation sensing areas, respectively; the processor processing the first and second output signals to obtain an indication of the amplitude of oscillation of the object.

2. Apparatus according to claim 1, wherein the processor generates an output oscillation signal that is applied to the oscillating object to modify the oscillation amplitude of the object in response to the oscillation amplitude indicated by the processor.

3. Apparatus according to claim 2, wherein the output oscillation signal is input to a control device that controls oscillation of the object.

4. Apparatus according to claim 3, wherein the control device compares the oscillation amplitude with a reference value and controls the oscillation of the object so that the object oscillates at an amplitude substantially equal to the reference value.

5. Apparatus according to claim 3 or claim 4, wherein the oscillation amplitude is controlled in real time.

6. Apparatus according to any of claims 1 to 5, wherein the width of each of the first and second optical radiation sensing areas is greater than the sum of half the width of the oscillating object and the amplitude of oscillation of the object.

7. Apparatus according to any of the preceding claims, wherein the first and second optical radiation sensing areas are directed towards the optical radiation source.

8. Apparatus according to any of claims 1 to 6, wherein the first and second optical radiation sensing areas are not directed towards the optical radiation source and the detector further comprises an optical device to direct the optical radiation onto the first and second sensing areas.

9. Apparatus according to claim 7, wherein the first and second optical radiation sensing areas are adjacent each other.

10. Apparatus according to any of the preceding claims, wherein the oscillating object is a tip of an ultrasonic transducer for use in an ultrasonic welding machine.

11. A wire bonder comprising apparatus according to any of claims 1 to 9.

12. A wire bonder according to claim 11 when dependent on any of claims 3 to 5 or on any of claims 6 to 10 when dependent on any of claims 3 to 5, wherein the control device comprises an ultrasonic wave controller.

13. A method of detecting the oscillation amplitude of an oscillating object, the method comprising positioning an optical radiation source and an optical radiation detector on opposite sides of the object, the detector comprising first and second optical radiation sensing areas; illuminating the object with optical radiation from the source and processing first and second output signals from the first and the second optical radiation sensing areas to determine the oscillation amplitude of the object.

14. A method according to claim 13, wherein the first and second output signals are processed by comparing the sum of the first and second output signals with the difference between the first and second output signals.

15. A method according to claim 13 or claim 14, wherein the oscillating object is a tip of an ultrasonic transducer in an ultrasonic welding machine.

16. A method according to any of claims 13 to 15, further comprising controlling the oscillation amplitude of the oscillating object in response to the determined oscillation amplitude.

17. A method according to claim 16, wherein the oscillation amplitude is controlled by comparing the determined oscillation amplitude with a reference value and controlling the oscillation of the object to oscillate at an amplitude substantially equal to the reference value.

18. A method according to claim 16 or claim 17, wherein the oscillation amplitude is controlled in real time.

ABSTRACT

Apparatus for Detecting the Oscillation Amplitude of an Oscillating Object

Apparatus for detecting the oscillation amplitude of an oscillating object (3) includes an optical radiation source (9) and a detector (10) including first and second optical radiation sensing areas (24A, 24B) adjacent each other. The detector (10) and the optical radiation source (9) are adapted to be located opposite each other with the oscillating object (3) located between the source (9) and the detector (10) so that the object (3) blocks a portion of the sensing areas (24A, 24B) from receiving optical radiation from the source (9). A processor (18) coupled to the detector (10) receives first and second output signals representing the magnitude of optical radiation sensed by the first and second optical radiation sensing areas (24A, 24B), respectively. The processor (18) processes the first and second output signals to obtain an indication of the amplitude of oscillation of the object (3).

Figure 2

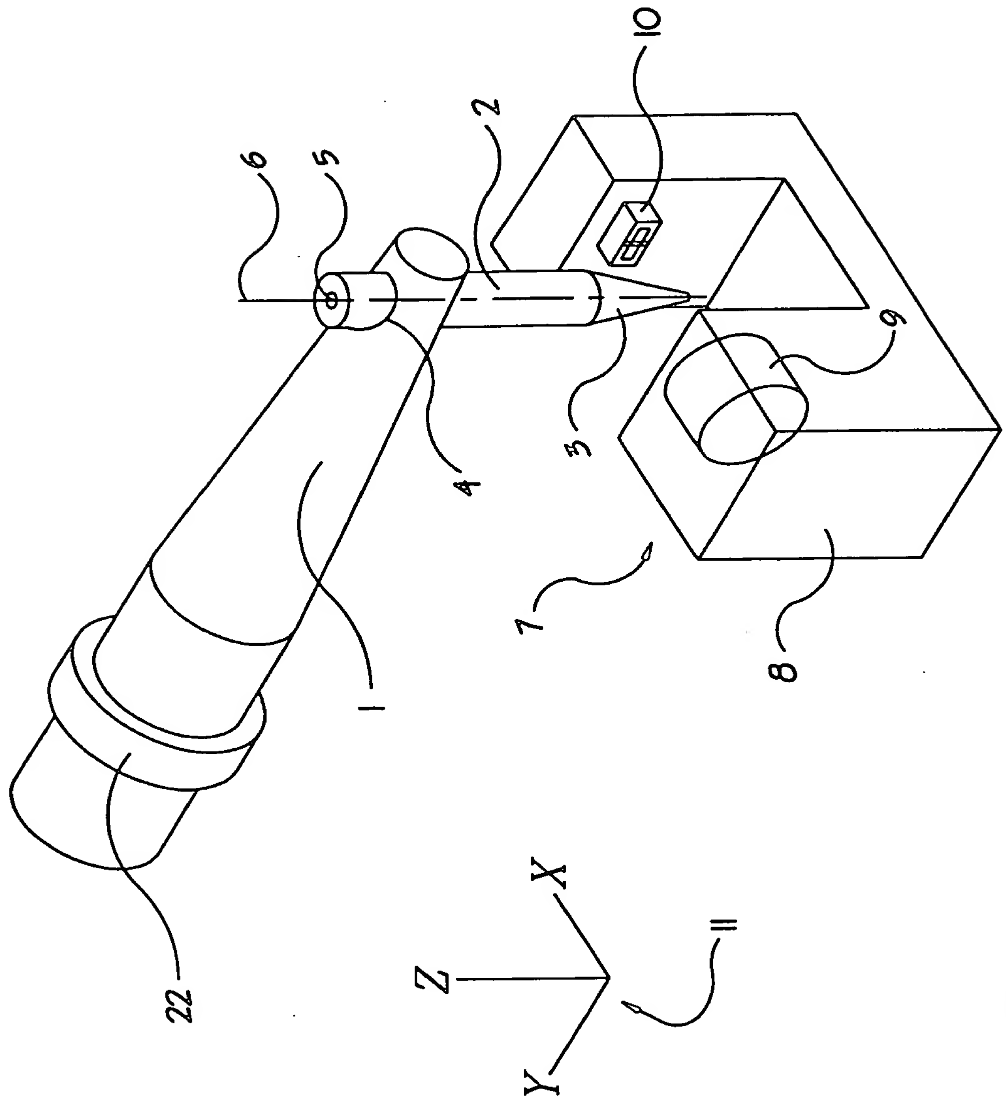


FIGURE 1

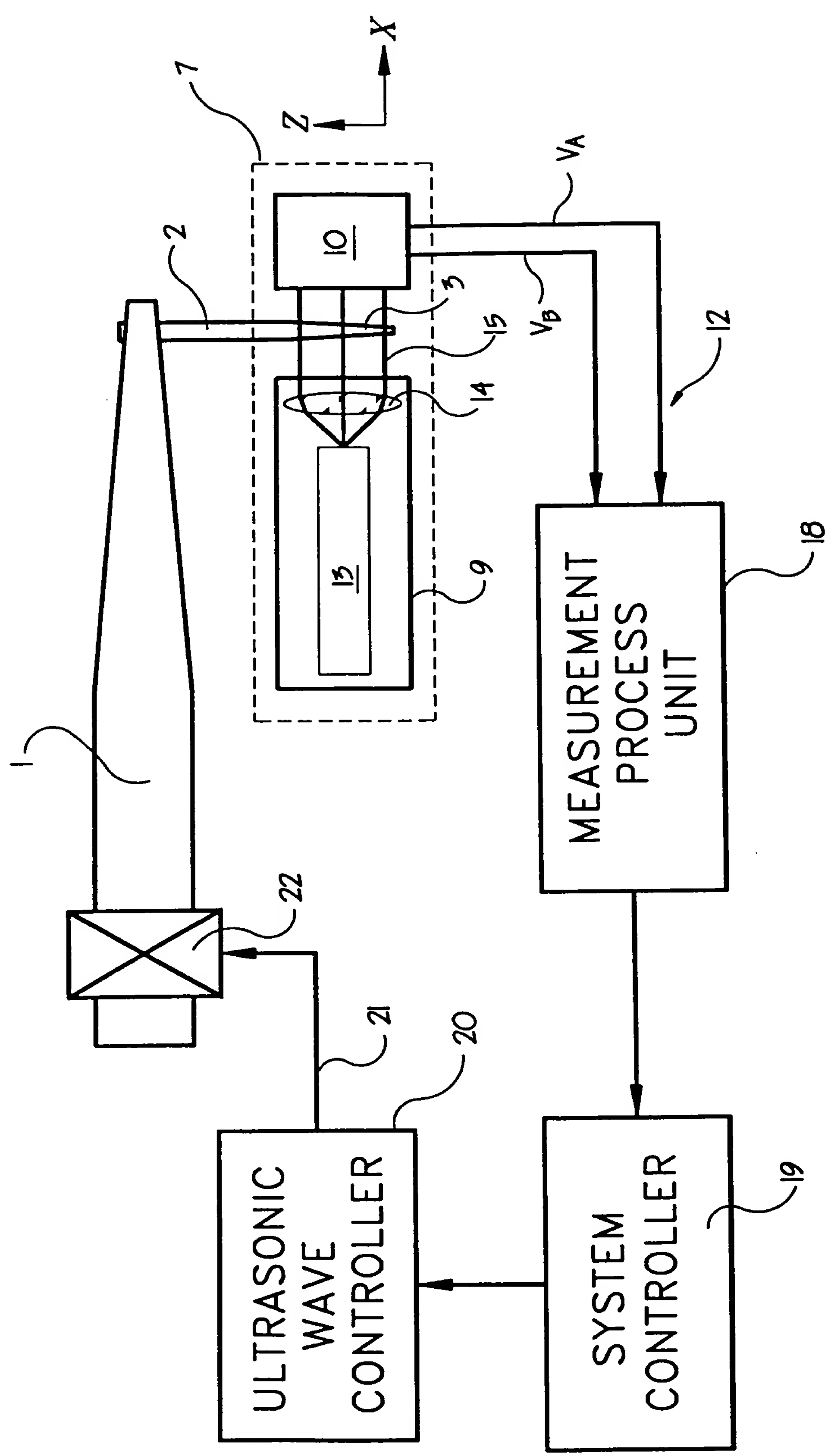

X
Z
7
VA
2
10
3
VB
15
12
14
13
9
18
MEASUREMENT
PROCESS
UNIT
1
22
21
20
ULTRASONIC
WAVE
CONTROLLER
SYSTEM
CONTROLLER
19

FIGURE 2

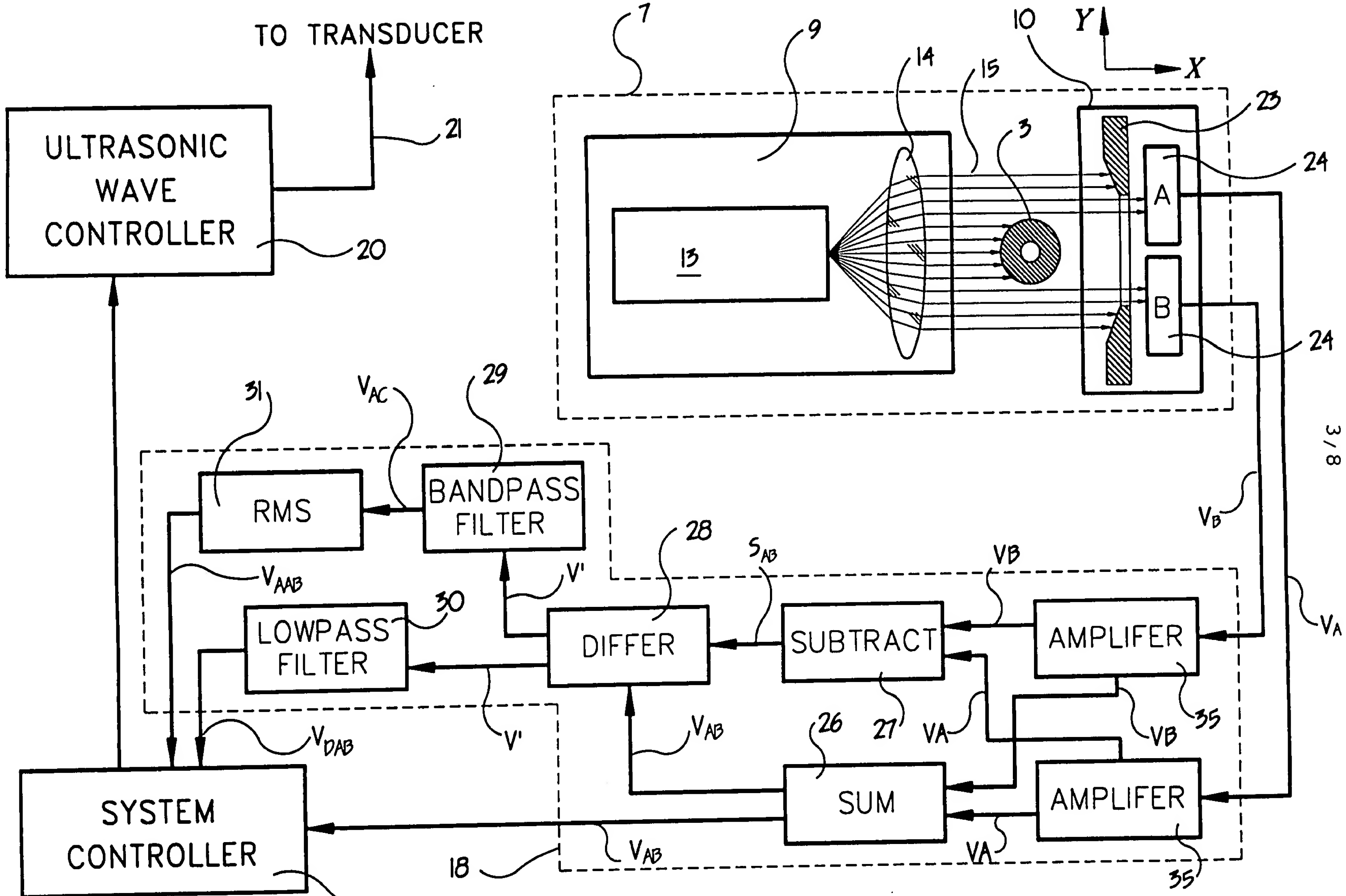

TO TRANSDUCER
ULTRASONIC WAVE CONTROLLER
21
20
7
9
13
14
15
3
10
Y
X
23
A
B
24
24
RMS
BANDPASS FILTER
LOWPASS FILTER
DIFFER
SUBTRACT
SUM
AMPLIFER
AMPLIFER
SYSTEM CONTROLLER
31
29
30
28
26
27
35
35
18
19
V_{AC}
V_{AAB}
V_{DAB}
V'
V'
S_{AB}
V_{AB}
V_{AB}
VB
VB
VA
VA
V_B
V_A

FIGURE 3

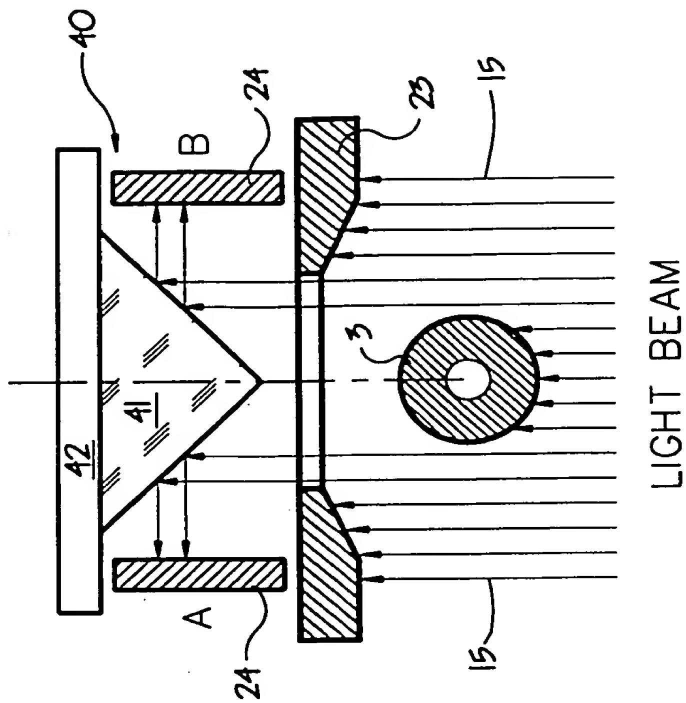


FIGURE 6

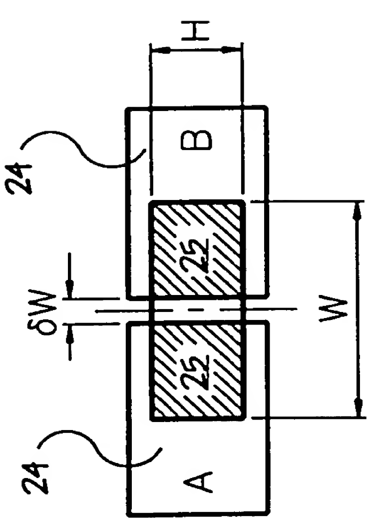


FIGURE 4

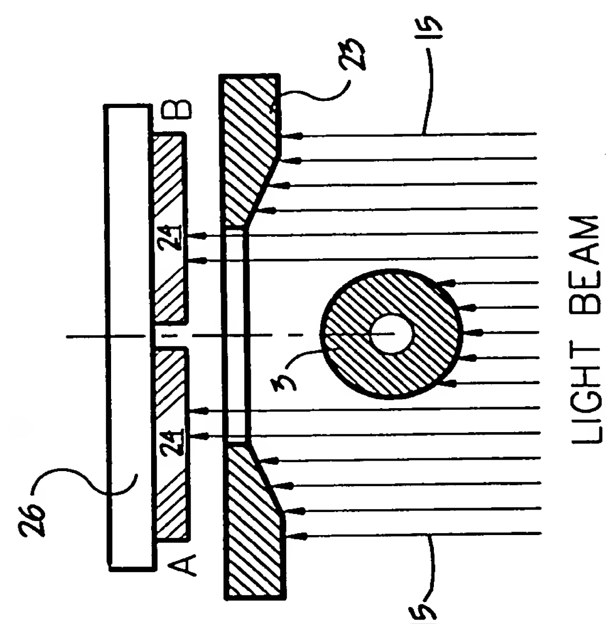


FIGURE 5

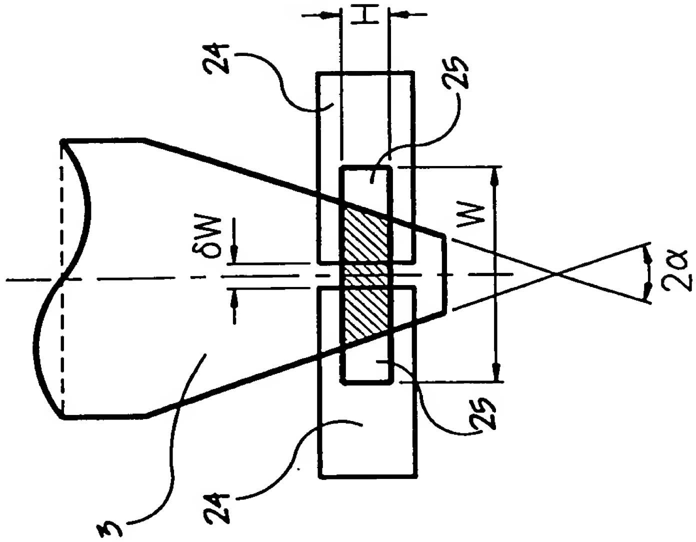


FIGURE 7A

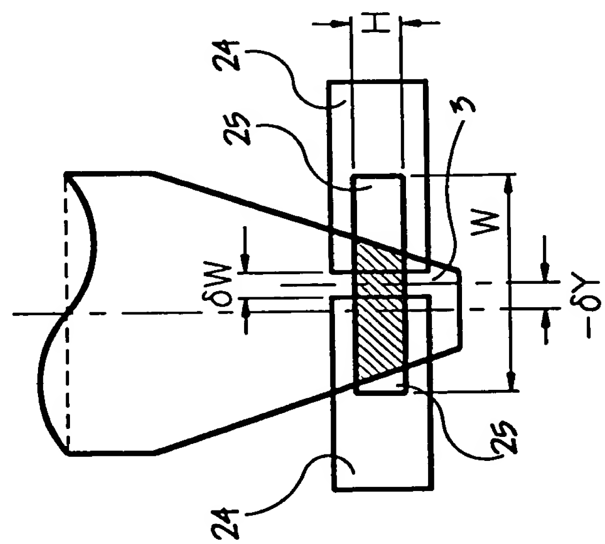


FIGURE 7B

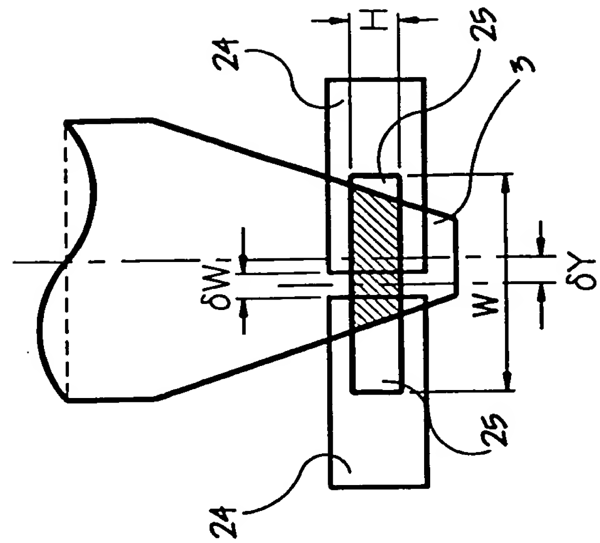


FIGURE 7C

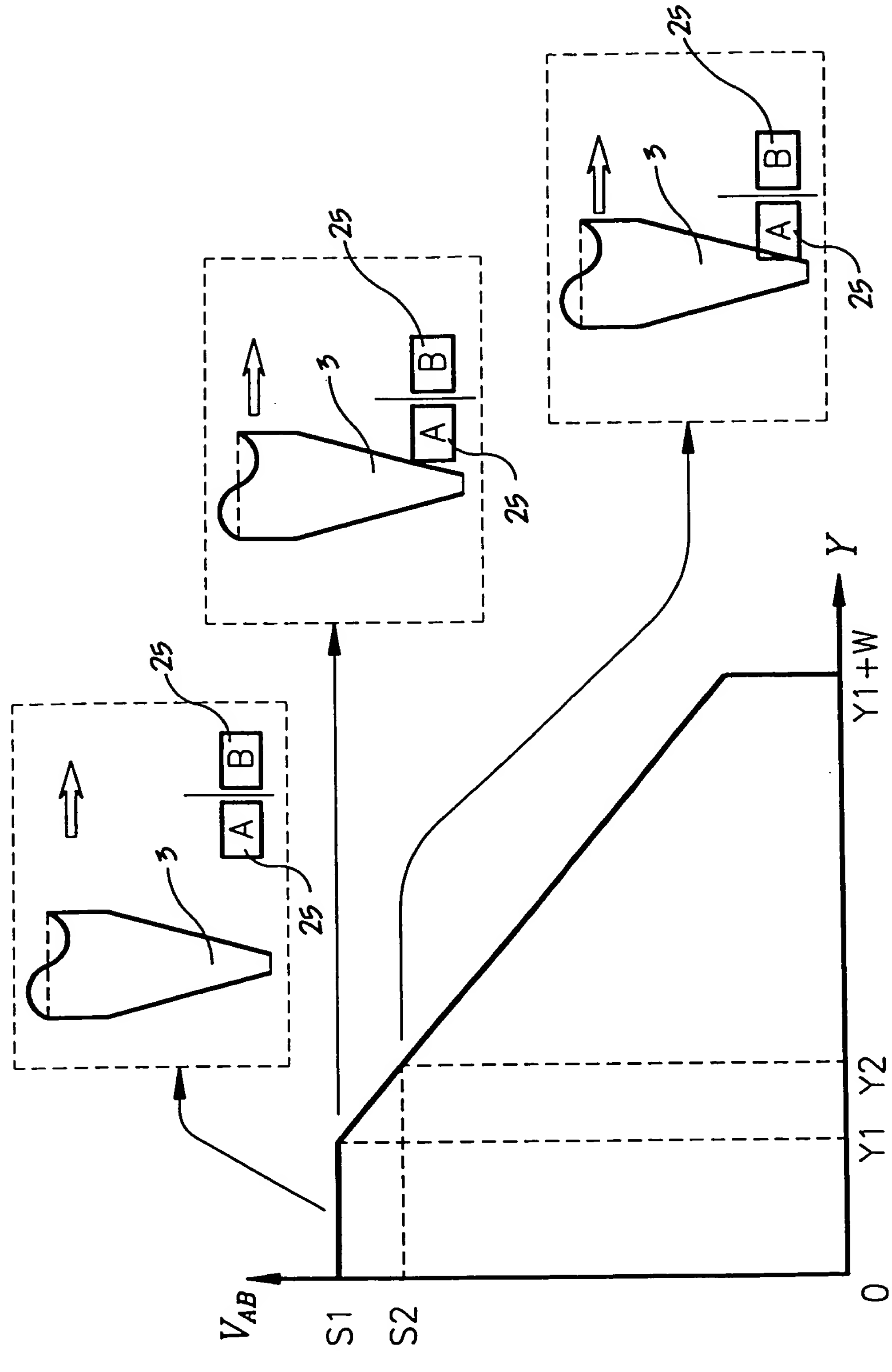


FIGURE 8

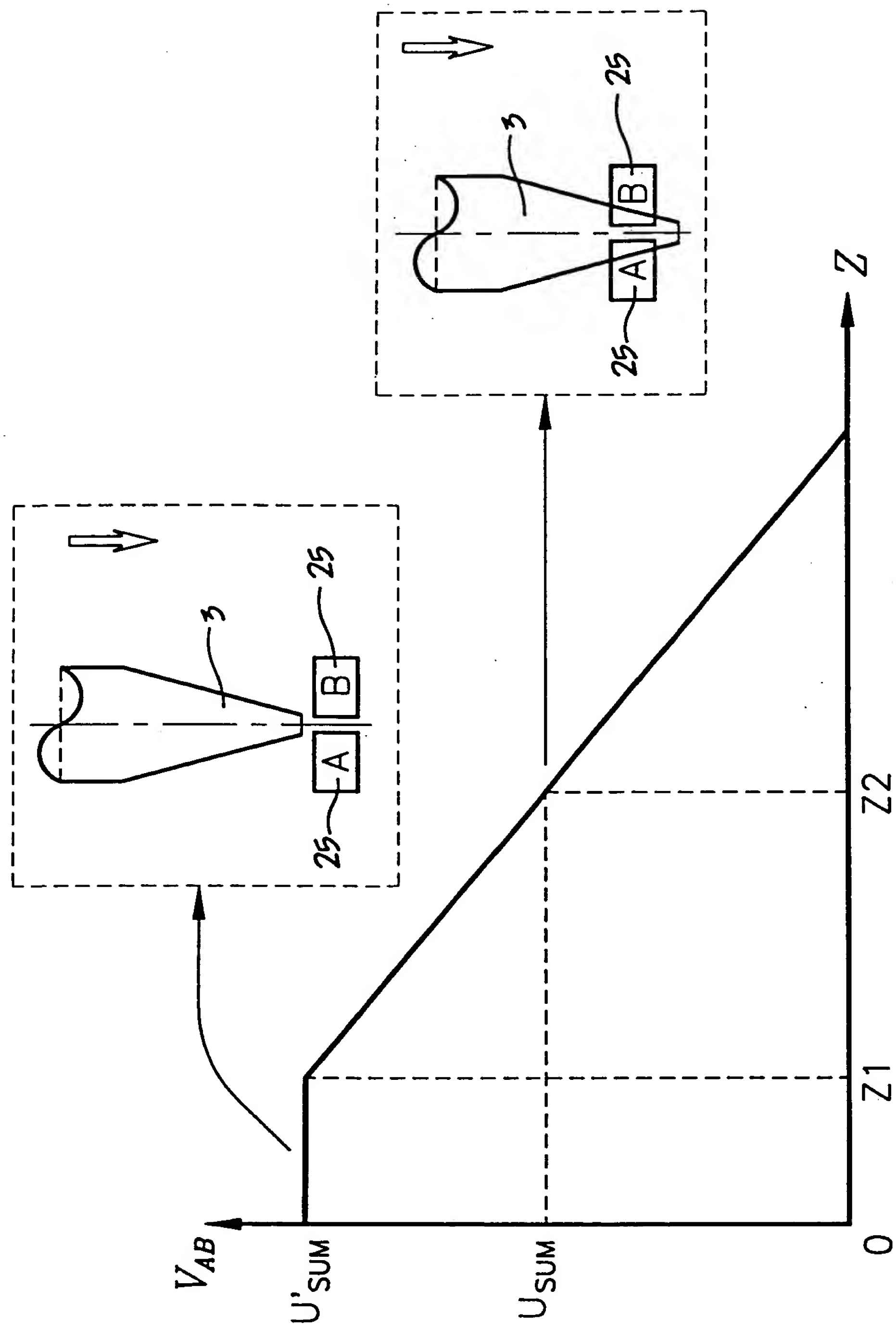
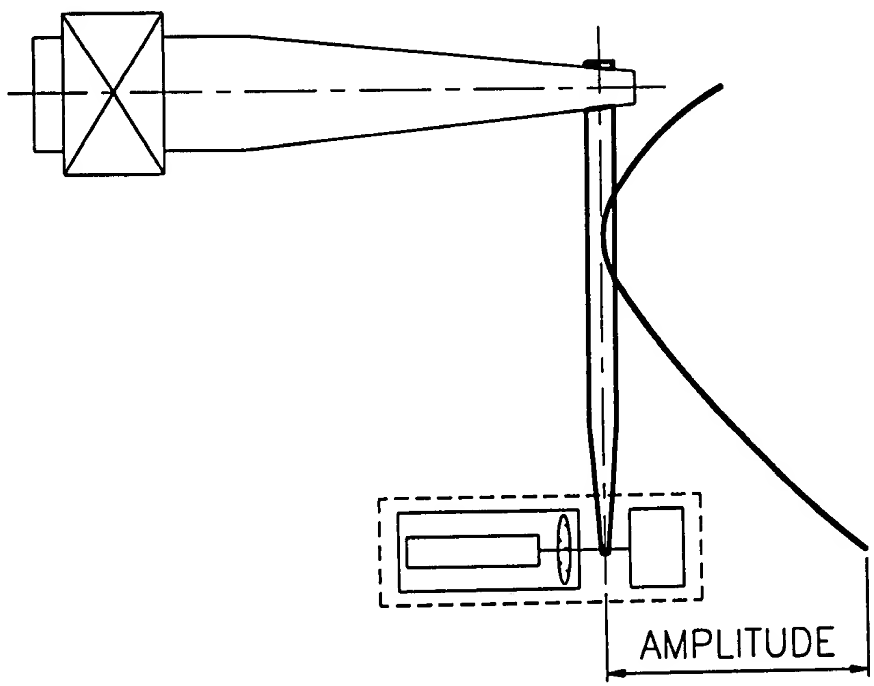
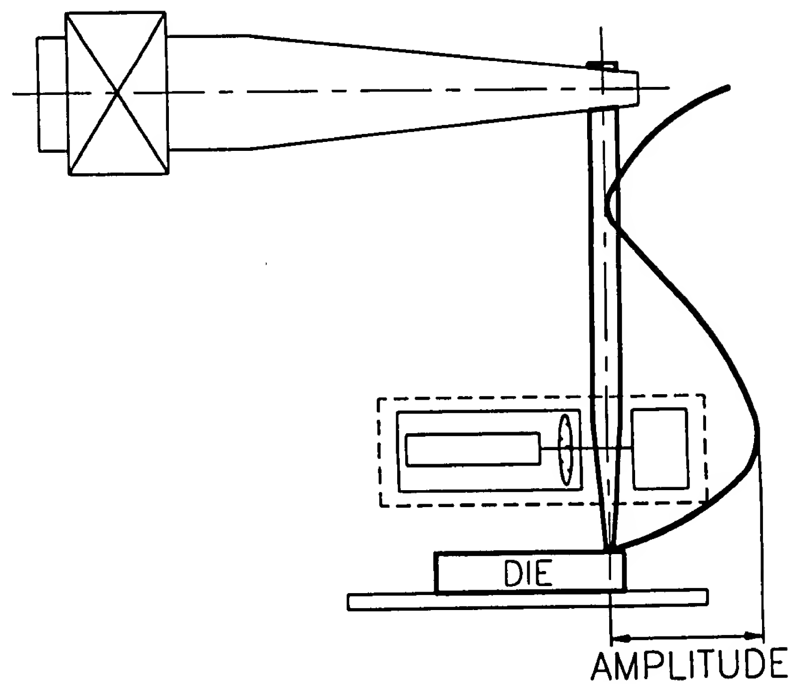


FIGURE 9



FREE VIBRATION
CALIBRATION

FIGURE 10



DURING BONDING
MEASUREMENT

FIGURE 11

PATENT COOPERATION TREATY

PCT

REC'D 15 AUG 2000
WIPO PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference FP1157	FOR FURTHER ACTION — see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/SG 99/00139	International filing date (*day/month/year*) 8 December 1999 (08.12.1999)	(Earliest) Priority Date (*day/month/year*)
Applicant ASM Technology Singapore Pte Ltd. et al.		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 4 sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**
   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.
      ☐ the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).
   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing:
      ☐ contained in the international application in written form.
      ☐ filed together with the international application in computer readable form.
      ☐ furnished subsequently to this Authority in written form.
      ☐ furnished subsequently to this Authority in computer readable form.
      ☐ the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
      ☐ the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.
2. ☐ **Certain claims were found unsearchable** (See Box I).
3. ☐ **Unity of invention is lacking** (See Box II).
4. With regard to the **title**,
   ☒ the text is approved as submitted by the applicant.
   ☐ the text has been established by this Authority to read as follows:
5. With regard to the **abstract**,
   ☒ the text is approved as submitted by the applicant.
   ☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.
6. The figure of the **drawings** to be published with the abstract is Figure No.: 2
   ☒ as suggested by the applicant.
   ☐ because the applicant failed to suggest a figure.
   ☐ because this figure better characterizes the invention.
   ☐ None of the figures.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG 99/00139

CLASSIFICATION OF SUBJECT MATTER

IPC[7]: B 23 K 20/10; H 01 L 21/607

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC[7]: B 23 K 20/10; B 24 B 49/16; H 01 L 21/607

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5431324 A (KAJIWARA) 11 July 1995 (11.07.95) fig.4.	1
A	US 5101599 A (TAKABAYASI) 7 April 1992 (07.04.92) abstract.	1

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
„A" document defining the general state of the art which is not considered to be of particular relevance
„E" earlier application or patent but published on or after the international filing date
„L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
„O" document referring to an oral disclosure, use, exhibition or other means
„P" document published prior to the international filing date but later than the priority date claimed

„T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
„X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
„Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
„&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 July 2000 (04.07.2000)	11 August 2000 (11.08.2000)

Name and mailing adress of the ISA/AT	Authorized officer
Austrian Patent Office Kohlmarkt 8-10; A-1014 Vienna Facsimile No. 1/53424/535	Bencze Telephone No. 1/53424/373

Document US 5431324 A relates to an ultrasonic bonding apparatus and quality monotoring method.
Document US 5101599 A discloses an ultrasonic machine having amplitude control unit.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/SG 99/00139

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US A 5101599	07-04-1992	DE A1 4121148	09-01-1992
		JP A2 4063668	28-02-1992
US A 5431324	11-07-1995	JP A2 5206224	13-08-1993
		JP B2 2705423	28-01-1998